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Dimensions of Effective STEM Integrated Teaching Practice

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Abstract

While there is widespread agreement about the importance of STEM, it remains an ambiguous term, particularly in education. We know little about what integrated STEM instruction looks like in the classroom, and how teachers conceptualize and implement integrated STEM. We conducted a small-scale case study with six participants to better understand salient features of STEM instruction and their variations in Thai classrooms. Drawing from multiple data sources, we identify four critical dimensions of effective teaching practice that distinguish and represent a teacher's ability to teach integrated STEM. We consider the relationship between these dimensions and pedagogical content knowledge (PCK) for STEM, as well as possible implications for future professional development related to integrated STEM teaching.

Keywords: Dimensions of Practice; Pedagogical Content Knowledge (PCK); Professional Development; STEM Education

Historically, the acronym STEM has been used to refer to the fields of science, technology, mathematics, and engineering. More recently, various iterations of the acronym (e.g., STEAM) have extended to encompass agriculture, the arts, the environment, economics, education, and medicine as well (Zollman, 2011). The acronym has also been adopted by governments, educators, businesses, communities, and industry leaders to communicate an urgent need for educating students and preparing them for college and the workforce. A broad understanding of STEM is important for students, as we live in a world that is defined to a large degree by science and technology. For example, the National Research Council (NRC) committee argued that "The primary driver of the future economy and concomitant creation of jobs will be innovation, largely derived from advances in science and engineering...4 percent of the nation's workforce is composed of scientists and engineers; this group disproportionately creates jobs for the other 96 percent" (2011, p. 2). A population that can make scientifically informed decisions serves to help everyone, as the economic and social benefits of scientific thinking and STEM education are widely believed to have broad application for workers in both STEM and non-STEM occupations (Gonzalez and Kuenzi, 2012).

Despite widespread agreement about the importance of STEM, there is not widespread agreement about its meaning, particularly in education. While definitions vary, however, there are areas of commonality. For example, most definitions include descriptions of an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school and community (Tsupros, Kohler & Hallinen, 2009). What this looks like in the classroom, however, remains unclear.

One of the biggest educational challenges for K-12 STEM education is that few general guidelines or models exist for teachers to follow regarding how to teach using or applying STEM integration approaches in their classroom. Furthermore, research into teachers' current integrated STEM teaching practices can inform STEM education stakeholders and assist in identifying barriers as well as determining best practices.

Aim of the Study

The aim of the present study was to explore, through a series of small-scale cases of STEM instruction, salient features of integrated STEM teaching and their variations. In approaching this work, we were conscious of various conceptions of what integrated STEM teaching should or could be, but were also intent on understanding integrated STEM teaching in the context of real classrooms and how teachers' conceptualizations of integrated STEM play out in practice. For example, the STEM roadmap (Moore, Johnson, Peters-Burton, & Guzey, 2015) proposes six key elements of integrated STEM teaching: (a) motivating and engaging context; (b) engineering design challenges; (c) learning from failure; (d) standards-based math and/or science learning objectives; (e) student-centered instruction; and (f) focus on teamwork and communication. A product of recommendations from STEM educators and STEM leaders, the STEM roadmap is intended to guide curriculum development efforts (Moore et al., 2015). In contrast, we sought to ground our work in empirical evidence of teachers' actual STEM lesson implementation. Specifically, we asked: "What features characterize teachers' implementation of integrated STEM?" and "How do those features vary among teachers who are implementing integrated STEM lessons in different contexts?"

Methodology

We conducted an instrumental case study (Baxter & Jack, 2008) to facilitate our understanding of the process of integrated STEM teaching. We used a single case design with embedded units (teachers) to enable a richer understanding of integrated STEM teaching from data analyses within, between, and across cases. Consistent with Yin (2003), we operated under the proposition that integrated STEM teaching is a multidimensional and complex process. We also acknowledge that effective integrated STEM teaching requires teachers to draw on a variety of knowledge bases, or pedagogical content knowledge (PCK) for STEM. Shulman (1986) theorized a specialized knowledge base for teaching and defined pedagogical content knowledge as "subject matter knowledge for teaching" and "the ways of representing and formulating a subject that make it comprehensible to others" (p. 9).

PCK for STEM is proposed and conceptualized based on extension of several scholars' notions such as Grossman (1990), Tamir (1998), Magnusson et al. (1999), Park & Oliver (2008), and Saxton et al. (2014), and consists of five components (see Table 1).

Table 1
Pedagogical Content Knowledge for Teaching STEM Education.

Components	Descriptions
1) Orientations Toward Teaching STEM	Teachers' knowledge and beliefs about the purposes and goals (orientations) for teaching and learning STEM: a) process, b) activity-driven, c) project-based science, d) inquiry and e) guided inquiry.

Components	Descriptions
2) Knowledge of STEM Curriculum	Knowledge of goals and objectives includes teachers' knowledge of goals and objectives for students in STEM concepts across disciplines (Science, Mathematics, and Technology). It also includes the knowledge teachers have about what students have learned and what they will learn afterward. Knowledge of specific curricular programs and materials: in this category, a teacher need to know about the activities and materials to be used in meeting those goals and objectives of STEM concepts that are organized for learning.
3) Knowledge of Students' Understanding in STEM	Knowledge of requirements for learning consists of teachers' knowledge and belief about students' prerequisite knowledge for learning a STEM lesson. This component also includes knowledge of students' conceptions of particular topics, learning difficulties, motivation, and diversity in ability, learning style, interest, developmental level, and need. Knowledge of areas of student difficulty refers to teachers' knowledge of the STEM concepts or topics that students find difficult to learn including students' misconceptions.
4) Knowledge of Instructional Strategies and Representations for Teaching STEM	Subject-specific strategies are general approaches to instruction that are consistent with the goals of STEM teaching, and related to the "orientations toward teaching STEM". Topic-specific strategies refer to specific strategies that apply to teaching particular topics within a domain of STEM concepts. These strategies can be divided into two elements: Topic-specific representations and Topic-specific activities.
5) Knowledge of Assessment of STEM Learning	Knowledge of the dimensions of STEM learning to assess refers to teachers' knowledge of the aspects of students' learning that are significant to assess within a particular unit of study, i.e., STEM. Knowledge of the methods of assessment refers to teachers' knowledge of methods of assessment that includes knowledge of specific instruments, approaches, or activities that can be used during a particular unit of study to assess important dimensions of STEM learning.

The components of PCK for STEM reflect important factors for teachers: how they view and conceptualize STEM education, how they understand the position of STEM in curriculum standards and educative materials, the establishment of STEM concepts among student learning outcomes, general understanding of students' conceptions and difficulties related to STEM, the creation of STEM teaching strategies and materials, and assessment of students' learning through STEM instruction.

Context of the Study

The study took place in Thailand, a country that is encouraging the implementation of STEM education via the Institute for the Promotion of Teaching Science and Technology (IPST) National Center for STEM Education. With the Thai government's intention to advance STEM in the country (see IPST 2013; NSTI 2014), this represents a major initializing period for STEM education. In 2016, IPST funded a series of professional development programs to support the development of teachers' PCK for integrated STEM. One such program consisted of a 3-day face-to-face workshop followed by monthly meetings during the academic year. The 3-Day workshop focused on developing participants' knowledge and skills involved in STEM teaching. The focus of Day 1 was on learning about STEM education, the nature of science, engineering design to investigate ways of integrating scientific and engineering practices into their content instruction and also focused on application of mathematic and technology into the STEM approach. Day 2 focused on STEM activities that teachers experienced as learners, followed by analyzing lessons to construct shared guidelines for designing STEM lesson plans. On Day 3 teachers shared a STEM lesson they designed and received feedback and suggestions for improvement from peers and facilitators. At the end of Day 3, teachers planned for implementation of their lesson and possible action research topics. Throughout the academic year, teachers met on a monthly basis to share and reflect on their implementation and outcomes of their action research.

Participants included six of the 29 teachers from Suphanburi province (Educational District 2) who participated in the PD program and consented to be part of the study. They represent a range of years of teaching experience and school contexts. Table 2 provides details of the participants in the study.

Table 2
Participants in the study.

Name*	Gender	Age	Degree	Years of Teaching Experience	School Type	School Size[1]	Average Class Size
Aof	male	47	Master's/ curriculum	17	urban	large	30
Suni	female	44	Master's/ science education	11	urban	medium	32
Tan	male	26	Bachelor's/ science	2	suburban	small	12
Yui	female	54	Master's/ science education	32	suburban	large	35
Fon	female	29	Master's/ education management	7	urban	small	20
Oh	female	31	Bachelor's/ animal science	1	suburban	medium	14

**pseudonyms*
[1]Large school size refers to an enrollment of 1,500 or more students; medium to 500 - 1,499 students; and small to fewer than 500 students.

Data sources and Data Analysis

Consistent with case study design, we used multiple data sources to enhance data credibility (Patton, 1990; Yin, 2003). These included:

1. Surveys collected prior to and following teachers' participation in the PD program;
2. STEM lesson plans designed by teachers;
3. Observations and video recordings of teachers' implementation of the lessons, as well as artifacts of instruction, e.g., student work;
4. Semi-structured interviews;
5. Teachers' written reflections; and
6. Recordings and notes from focus-group discussions at the end of the implementation period.

The pre- and post-surveys focused on teachers' perceptions about STEM education and perspectives of STEM integration for teaching. Teachers' STEM lesson plans included learning objectives, an overview of the lesson, and detailed instructional plans; however, these varied in terms of whether teachers addressed the goals in a single or multiple classroom sessions. A total of 28 lesson plans were collected. Classroom observations of each participant were conducted 1-3 times, depending on the structure of their lessons. We video recorded lessons and collected classroom artifacts including handouts, student work, and teachers' reflective journals. Interviews were conducted pre-workshop, post-workshop, pre- and post-lesson implementation, and during reflection meetings. Semi-structured protocols were developed based on survey responses and a review of the literature. Topics for the focus-group discussions were developed based on identification of common or recurring issues from surveys, interviews, and classroom observations.

All data were transcribed and systemically organized into electronic files. For each videotaped lesson, a summary narrative was established, which identified the main actions of the teacher and students. Our initial method was to adopt a grounded approach (Strauss & Corbin, 1990), allowing themes and analytic categories to emerge through an iterative process of engagement and re-engagement with the data. For triangulation of data, we rechecked all data and cross-checked with other sources for variations on themes that emerged from our analysis.

While analyzing the summary narratives, we focused on features that distinguished effective from less effective lessons and a search for correspondence and patterns (Stake, 1995). We carefully sought to identify common aspects in the behavior and styles of the different teachers that were reflective of PCK for teaching STEM. We developed categories based on commonalities, for example, teachers' ability to connect STEM content to the learning activity. After that, we performed a second round of analysis in which categories were triangulated against other data-sets such as lesson plan analysis, interviews, teacher reflective journals, and others.

Findings

According to our analysis, we extracted the common patterns of actions in STEM classrooms and systematically organized the noticeable patterns as a series of dimensions. Ultimately, we constructed four dimensions of effective STEM teaching practice. In each dimension, the continuum of actions are identified and shown from weak to strong practice, from left to right (Figure 1).

1. Teacher's Role and Instruction		
Student-centered; grapple with content and think for themselves		
Closed and Authoritative	<------------------>	Open/Dialogic
2. STEM Learning Context		
Meaningful, motivating, linked to real world and STEM careers		
Contrived/Inauthentic	<------------------>	Authentic/Real world
3. Student Engagement in Design Process		
Iterative, allow for failure, refining ideas, teamwork, communication, 21st Century Skills		
Focus on Product	<------------------>	Focus on Students' Ideas
4. Connecting to Content		
Integration of key concepts in STEM disciplines learning through engagement in engineering design		
Process Only	<------------------>	Deep Content Learning
Weak	***continuum***	***Strong***

Figure 1. Four dimensions of STEM teaching practice.

Each of these aspects had an impact on the nature of the learning experience during the sessions we observed. Thus, we described explicit evidences that were used to consider and discuss details about each dimension. We note that the position of teachers across each of the dimensions can shift across time. However, we believe these dimensions can be used to characterize teachers' actions in order to compare different approaches to teaching STEM. Furthermore, we can connect each dimension of STEM practice to each of the components of PCK for STEM to explore the relationship between teacher action and teacher knowledge.

Dimension 1. Teacher's Role and Instruction

The first dimension is supported by data obtained principally from classroom observations, teacher interviews, and reflection meetings. Our belief was that STEM instruction requires an opportunity to engage in epistemic dialogue with others, i.e., one's peers or a teacher. Like science, a student-centered approach should be used to enhance student's participation. There are many strategies that teachers can apply such as posing challenge questions to further student thinking and having students grapple with contents and think for themselves to answer the questions.

We observed that data from classroom observations of teachers during the implementation period elucidated the differences between the teachers. One of the teachers (Aof), for a strong example, showed particular concerns in engaging in dialogic discourse and posing essential questions with students. Aof always posed a lot of open-ended questions during his instructions. He used questions to challenge students, checked students' background knowledge and understanding, engaged them in the design process, and connected to STEM content and careers. Compared to other participants, Aof posed questions during every step of his STEM lessons: defining problems, developing solutions, redesigning, and communicating results. Moreover, data from his interviews pointed out that he strongly believed that the best STEM activity is an activity in which students have to think and learn by themselves and that the teacher is only a facilitator (helper and observer). Aof expressed a positive attitude about his teaching experiences as well.

Int. Why did you ask a question while students were drawing up a solution?

Aof I asked a lot of questions because I wanted to know what they were thinking and what the concepts or contents were that they applied to think about the solution. I think by asking questions students have to think and explain to me some answers that relate to contents that I intended to teach them. But sometimes it is hard to find the right questions that bring about those answers; I think it will get better when I have more experiences by teaching this again.

As a contrasting example, we consider the lesson instructed by Yui, who taught in much larger classrooms, between 35 to 43 students per class. She mentioned at the reflection meeting that she had little chance to ask students questions and had no time for discussion about what they had learned during the lesson. She felt that STEM activities require a lot of time to teach and that teachers need to be well prepared before teaching. In her activity about gliders, students worked in groups of 4-5 to make a glider based on teacher's direction and information. Students merely followed the steps that were created by the teacher, and responded to closed-ended questions, for example, "Do you think a big paper circle can make your glider fly longer than using small one?" From this question students did not need to think; they just built and tested the glider to find the answer. In the focus group discussion, Yui told the group the following.

Yui I know my teaching was not a good instruction for students. I do not think it can be called STEM. I think I should give students a chance to express their thinking. Next time, I will give them papers to draw somethings while they are planning and doing their work. But I could not do those this time because of time

> *limitation. I think I might be better if I divide my activity into several times and add more times for students to talk and discuss with their classmates.*

In reflection, Yui felt she knew what was wrong with her lesson and ways in which to improve her instruction. She committed to continue teaching STEM in the next semester while adding some "essential questions" to enhance her student-centered approach and to rearrange activities in the lesson to consider a suitable time schedule for the whole unit.

Dimension 2. STEM Learning Context

The second dimension arose from the lesson plan analysis and interviews both during and after implementation. To connect lesson plans to real life situations in practice, teachers need to create a learning context that is meaningful, motivating, linked to the real world and STEM careers. In lesson plan analysis data, we noted key differences in the context of teachers' lessons. For example, some teachers used authentic situations to motivate students and linked the situations to student's everyday lives. Additionally, the lessons contained connection points to STEM related jobs and STEM content.

We analyzed 28 lesson plans from teachers who attended our face-to-face workshop and divided these into five categories (Table 3). The largest percentage of teachers developed and implemented lessons that integrated science and mathematics through engineering design (39.29%). The second largest category consisted of design challenges (10.71%), such as the activity called Hulk's tower, in which students have to build the tallest paper tower by using limited resources. After building, they only measured the height of towers—but did not connect it back to science and mathematics content.

Table 3
Categories of the STEM lessons proposed by teachers.

Category	Description	frequency	Percentage
Project-based lessons grounded in real-world problems	The lesson focuses on a problem or project-based learning is incorporated through a realistic context without any connection.	4	14.29
Science and math integrated through engineering design	The lesson addresses science and math contents incorporated with engineering design process	11	39.29
Engineering design tasks without an explicit link to content	The lesson follows an engineering design process but is missing the address to appropriate content.	8	28.57
Design challenges	The lesson does not follow an engineering design process, including only building and testing without needing to apply content information	3	10.71
Science-only activities	The lesson is a science activity, but is missing connections to other disciplines	2	7.14
	Total	28	100.00

Several lesson plans can be strong examples of this dimension; one of them is a lesson taught by Aof, in which he used a "bua-loi" (a popular Thai gelatin dessert) activity as a vehicle for teaching about concepts of foods and nutrition. He began by showing a video clip about food contamination by using artificial color. He then asked students to discuss food safety and the ways to avoid consuming all those contaminated foods. Students were encouraged to design suitable recipes for cooking "bua-loi" with scientifically appropriate nutrition that meets clients' needs (e.g., carbohydrate, fat, and protein) and product packages as well. After that students investigated science content, i.e., the daily value of each person's nutrition needs that are also dependent on other factors such as age, sex, activities, etc. Mathematics concepts were integrated by calculating percentage and ratio of nutrition per serving. Students developed both specific proportion of nutrition and product packaging through engineering design. In this lesson, Aof used a common context that could catch learners' interest and motivation. In addition, Aof also reported to us and other participants at the reflection meeting that gender probably affected students' interest level in a specific activity. He noticed that female students seemed to be more enthusiastic than male students. In this manner, he was considering how the context of his lesson connected with his students' interests and lives.

For a weaker example, a lesson was taught by Yui, called Air Rocket (example of Design Challenges Category). She started by giving students the directions for building an air rocket by using two sizes of plastic straws and artificial clay. She set criteria for rockets that required a launch and flight longer than 3 meters. Afterward, students began building and testing their air rockets. Correlated with our observation of this activity, she used a contrived circumstance in that students only followed directions shaped by the teacher. However, students seemed to enjoy doing the activity but they had no chance to discuss reasons during the activity and connect their lesson to real life situations. Moreover, we noticed that Yui was worried about time and class-room management. So, she rarely asked questions or discussed with students during the activity.

Dimension 3. Student Engagement in Design Process

In a STEM lesson, students should be engaged in a design process (engineering design process) that is iterative, allows for failure, allows refining ideas, and requires teamwork and communication. Some of the rationales for the inclusion of engineering in K-12 coursework include the following: 1) Engineering provides a real-world context for learning mathematics and science; 2) Engineering design tasks provide a context for developing problem-solving skills; and 3) Engineering design tasks are complex, and as such, promote the development of communication skills and teamwork. (Brophy et al., 2008; Hirsch, Carpinelli, Kimmel, Rockland, & Bloom, 2007; Koszalka, Wu, & Davidson, 2007)

Although in many of the lessons analyzed and observed data suggest that most of the STEM lesson plans in this study consisted of a design process, not many of these lesson plans covered all of the engineering design process, and not all of them performed relevant integrated engineering design. Based on Table 3 mentioned above, only 39% of lesson plans implemented by teachers integrated science and mathematics or other content areas through an engineering design process. The remaining lesson plans identified mismatched application for STEM instruction. It seems most of the teachers think they are teaching STEM but somehow they are truly not.

A strong example of this dimension is the lesson called "Water Heater" taught by Suni. She started the lesson by recalling students' background knowledge about heat transfer, proprieties of matter, and others, and engaging students by using video clips about solar energy and water heaters. She then gave students a challenge situation in which students had to build a water heater in an area where is no electricity, with a precise water temperature that the water heater had to achieve. In this lesson, there were several steps that covered engineering design, which are defining the problem, developing ideas and solutions, and testing and evaluating solutions with integration of proper contents in both science and mathematics. At the end of the lesson, Suni also checked students' content understanding with a problem-based exam in which students had to calculate some mathematics problems about mixtures of two different water temperature proportions. She explicitly focused on the process of forming a solution by requiring students to write down what happened in their design process that they experienced; she called it a "STEM journal".

In a weaker example, we observed Tan's lesson plan that he adapted from an EiE (Engineering is Elementary) activity called "Hulk's Tower". Actually, in the EiE version, this activity is the first activity of integrated engineering practice that is used to introduce engineering design to students. However, Tan modified by adding some steps to make it her STEM lesson plan. She started with the situation that students were required to build the tallest and strongest paper tower by using limited resources. Without design and content application, students just built paper towers and then measured the height and tested the strength by placing increasing mass on the top of tower. Students and teacher had no chance to discuss about what they had done and what they learned. Based on our observation, few students could connect the activity to content, but some connected to careers, for example, one of the students told his peers after the teacher asked, "I think this activity is similar to what architects do before other persons (workers and engineers) can start their jobs. They need to follow the design that is drawn by architects."

Another contrasting example that we would like to point out, is one that Fon taught, a lesson plan called "Soap Making" that we later defined as a science-only activity. She taught students about how soap is made and then gave students materials to make their own. Students began to make soap following a given procedure. Although Suni mentioned the science concept about saponification and chemical reactions, no other discipline connection nor engineering design existed in her lesson. The whole class focused only on the product that they made, without discussing the process of making soap. However, at the reflection meeting, Fon seem to give more attention to the engineering design process:

> *Fon "In a STEM lesson, students should be engaged in order to learn by themselves. We must start the activity by giving necessary information that will be useful for creating a solution. The activity should begin with defining the problem, giving criteria and constraints, designing, developing, and communicating a solution. We need to integrate technology (as tools) in our teaching, such as computers and mobile devices....If I am ready, I think I will use a STEM journal with my students to track what are they thinking and doing."*

From our data, we suggest that, like other dimensions, student engagement in a "design process" dimension can change across time while teachers are implementing. This is especially, we found, that teachers who often mentioned students' learning outcomes and STEM educational purposes seem to drift from the left to the right on the teacher or student centered continuum of the dimension.

Dimension 4. Connecting to Content

In the last dimension, we identified the right side of the continuum as "deep content learning" while the left side is defined as "process only". However, in this dimension, we only focused on describing how teachers view instructions and classified teaching styles. It does not mean that being on the right side is better than being on the left. In our opinion, there are several factors involved in this issue, for example, the teacher may set the learning objective narrowly to a process of learning so that teaching style may be defined as belonging on the left (process) side.

Therefore, the details of this dimension will focus on distinguishing between the two sides. For a strong example of integration of key concepts in STEM disciplines, once again, it is the lesson that Aof taught, the "bua-loi" activity. In terms of integration, he explicitly connected STEM disciplines to his lesson. For science, Aof designed an activity in which students need to research food nutrition for daily life depending on gender, age, and level of activities. For mathematics content, he integrated concepts that match students' usage such as average, percentage, and ratio calculations. For technology and engineering, Aof connected main ideas of using technology as the supporting tools and applying engineering design as the way that students can use to solve a challenging problem (designing and making meals that meet nutrition requirements for a specific group of people). He also added a challenging design activity, which was to design a package and logo of their foods or snacks. During an interview, Aof explained his rationale for implementation:

Int. Why did you assign students to design a product package and logo?

Aof I needed to emphasize the technology and engineering (design) integration of my lesson. I think it is a good way to do it, because the nutrition concept alone could not reach to that point.

We noticed that many teachers that participated in our project believe some concepts of science, especially in biology and earth science, are difficult to instruct by using the STEM approach. In other words, some contents are difficult to integrate directly with engineering design. Many scholars agree that teaching or integrating engineering concepts into lessons worries many science teachers (Haag & Megowan, 2015; Boesdorfer & Staude, 2016). Similar to our data, Banilower et al. (2012) argued that most science teachers have little or no experience with engineering.

On the left side of this dimension, for a weaker example, Yui, who taught the activity named "Bridge Making", began by giving students a design challenge situation whereby students had to build a bridge across a river (30 centimeters distance) by using only given materials. This lesson was designed to be taught in an hour. Thus, students had no opportunities for brainstorming ideas, thinking or even discussing. During classroom observations, we noticed that students only built their bridges by trial and error without any content mentioned.

In another lesson called "The Glider" that she also taught, she integrated Bernoulli's principle and other disciplines in her instruction. However, based on our STEM policy it was prioritized as a supplemental course. Thus, in the final reflection meeting, some teachers viewed STEM teaching as an extracurricular activity or a "process and skills" development activity.

Int. Which periods did you teach STEM in this semester?

Tan I taught STEM lesson in an after school program (Teach less-learn more policy). I taught it (Bridge Activity) two or three times a week for grade 5-7 students.

Int. In this activity, what are the main objectives or learning outcomes?

Tan My objectives were for students to gain a better attitude about STEM and develop some skills such as creativity and problem solving.

Int. How about you, Yui?

Yui I also taught in an after school program and science club course, because I think it is the best time for STEM. Also, it did not require any content integration. So, I just let my students do a fun activity.

Int. *What are the main objectives or learning outcomes in your lesson?*

Yui *I only focused on students' skills development such as problem solving, critical thinking, collaborating, and communicating. I am pretty sure that they gained some of them.*

Moreover, the data obtained in interviews about implementation suggest that teachers need to understand the content deeply themselves. Without clearly understanding content, teachers may be confronted with difficulty while they are teaching some specific content. For example, Suni had a problem teaching about the concept of elastic potential energy in her "Speed Boat" activity. She expressed concern about her explanation to students during the activity:

Suni *My physics knowledge is not quite good. Although I had to read so many times about it, I still felt anxiety when students asked further questions that I thought I may not know the answers. But, I did it...I believe that teachers need to prepare themselves for unfamiliar content or possible content that might come up while we teach STEM.*

Int. *Why?*

Suni *STEM teaching is such a student-centered activity. That makes it very difficult to shape our students to go in the way we would like. Many times they asked unexpected questions. So, that needs a lot of preparation and a deep understanding of some concepts.*

Discussion

Effective Practices

STEM should be viewed as a meta-discipline, the creation of a discipline based on the integration of other disciplines into a new whole (Kaufman, Moss, & Osborn, 2003; Morrison, 2006) and integrated instruction is any program in which there is an explicit assimilation of concepts from more than one discipline (Satchwell & Loepp, 2002). In our study, we focused on seeking and identifying the effective practices of teachers for teaching STEM.

According to our findings we strongly believe that teachers who attempt to teach STEM lessons will need support to develop sets of learning necessary for effective knowledge and skills that were extracted from our four dimensions of practice.

First, in Teacher's Role and Instruction Dimension, for engaging and motivating students and supporting student-centered learning, teachers need to develop the sets of "essential questions" that encourage students to think. The questions should be designed and arranged through the STEM learning process. For example, for defining a problem, teachers need to prepare a set of questions that challenges students to think about possible solutions. In the case of Aof, he asked students about necessary nutrients that everyone needs to meet the daily requirement, which reminded students to think about nutritional value in their products. Moreover, Aof posed further questions about suitable proportions of each nutrient for specific persons depending on age, gender, and activities. These kinds of questions can help teachers engage student learning as well as assess prior knowledge of students.

In the case of the Speed Boat activity, Suni asked students questions about the design process that enhanced students' critical thinking, communication, and collaboration skills.

Suni What are the materials that you selected to build your speed boat?

St. Um..I selected plastic forms and straws.

Suni Why did you select plastic forms?

St. The form will float on the water surface (based on prior activity).

Suni OK, how will you build it?

St. I will build the base first by...

Suni Hold on, how will people in your group understand the whole process of building this?

St. We can draw our design on paper and talk within the group.

Although we believe that teachers should ask open-ended questions in STEM activities, in some cases teachers taught that asking broad questions may be difficult to shape and manage the classroom. For example, in the Glider activity, Yui already had expected a solution to "Glider" for her students, thus she provided limited materials and asked narrowed down questions to guide students to think about it. However, at the reflection meeting, she agreed that starting with open ended questions then digesting them into small pieces afterward can draw students' attention and allow them to think. Preparing a set of essentials questions that guide students to expected procedures without them feeling required to do is one of the important strategies for teaching STEM.

Secondly, in the STEM Learning Context Dimension (Dimension 2), the teacher needs to develop content knowledge about STEM. This development is a long-term process but needed to be done eventually. Many engineering or STEM problems commonly involve specific content knowledge. For example, designing and making soap solutions in the "Herbal Soap" activity, required knowledge such as skin types and chemical properties which made the teacher, Fon, suffer from anxiety attacks during the activity.

Int. Why do you think content knowledge of the teacher matters?

Fon I am worried that when I am teaching some content, I am not good at it...in the soap activity, I was afraid that students would ask something that I have no ideas about.

In addition, we found that many teachers have some understanding about STEM careers and some indicated that they know how to find the information about it; few teachers have no ideas. We suggest that teachers be required to develop their understanding about STEM and STEM-related careers, as it can directly affect students' learning outcomes that involve attitudes about STEM careers and thereby increase the STEM workforce. If lacking these, teachers may have problems linking STEM activities to careers or life in the real world.

Thirdly, in Student Engagement in the Design Process Dimension (Dimension 3), it is clear that taking an integrated approach to teaching science using engineering design requires higher levels of conceptual understanding of both science and engineering and greater professional commitment than teaching science in a more traditional manner (Capobianco and Rupp, 2013). Unlike science and mathematics, engineering is viewed as a brand new concept and difficult to integrate in lessons. Thus, we suggest supporting teachers to improve their understanding of engineering design or design process and consider it as basic knowledge of teaching STEM, whereby teachers may need a period of time or even specific training to see how to integrate engineering in their lessons.

Lastly, in Connecting to Content Dimension (Dimension 4), we strongly believe that teachers need to focus on not only process or content of STEM in their lessons. All of students' learning aspects which are content, skills, and attitude should be considered important to develop while teaching. Similar to Fortus et al. (2004), we suggest that for teaching a STEM lesson both knowledge (content) and pedagogy must blend. Thus, for every model of effective STEM integration, the goal and intent is to provide students with the opportunity to construct new knowledge and skills through the process of designing artifacts. Teachers who hold a strong intent to develop students' competencies completely tend to have sufficient abilities for teaching STEM lessons more effectively than those focused on products of activity or incomplete student competencies. Knowing and focusing on student's outcomes can affect a teacher's practice. For example, Aof conducted action research in his classroom about students' outcomes for learning STEM. He needed to observe student capabilities that are developed by learning through STEM activities. The result is that he improved his understanding about students' outcomes and how to assess them as explicitly reflected from his PCK for STEM score, especially in the knowledge of assessment component.

Practice versus Knowledge

Although in this study we focused on identifying dimensions of effective STEM practice, we think that separating "what teachers know" from "how teachers do" is impossible. However, we found the relationship between the four dimensions of STEM practice and components of PCK for STEM. Figure 2 shows that teachers' practices relate to their knowledge, for example, Knowledge of instructional strategies (Instruction) shows that teachers who have a high level of understanding of diverse strategies including inquiry strategies to challenge student thinking are able to pose a challenge question, which supports students' motivation and ownership of actions in the lesson.

In another example, Knowledge of learner (Learner), a teacher who has a sophisticated understanding of the specific STEM topics based on students' context such as interest, grade level, and prior knowledge, can figure out several ways to engage students with those specific contexts. For example, Yui mentioned that most of her students were interested in being mechanics. She then designed her activity that emphasized mechanics' issues and provided a lot of information about this kind of career.

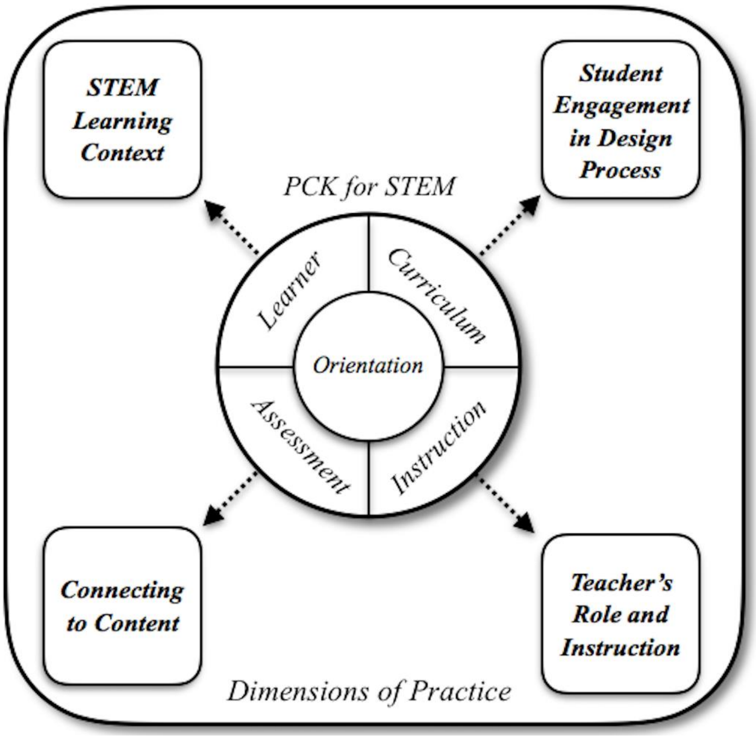

Figure 2. *Relationships between Dimensions of Practice and PCK for STEM*

However, further research is still needed on the relationship that we proposed in order to visualize the complex association among elements of practices and knowledge. We hope this unfinished work can help us improve understanding of teachers' perception of STEM education and how it affects their practices. Once we know more, we can create effective professional development opportunities that realistically help teachers teach STEM lessons with appropriate context.

In addition, some remarkable issues of STEM disciplines integration were observed, especially in technology and mathematics. Many times, participants experienced difficult situations when selecting suitable mathematics content that are compatible with student context. In these instances, teachers only applied familiar concepts of mathematics without considering standards. That makes sense, because they have few opportunities involving teaching beyond their teaching assignments and sometimes there is lack of collaboration among teachers. As Tan said at the reflection meeting:

> *I think teaching the lessons with unfamiliar contents (Mathematics) is very difficult, because I have no idea what they (other teachers) are teaching now. I only use simple concepts, like addition and subtraction, in my activity.*

However, we believe that lack of high quality mathematics integration may be a management issue rather than a teacher's knowledge or abilities. On the other hand, with technology integration, we noticed that the core of the problem probably comes from teacher's understanding or perception about technology. Technology concepts are quite confusing among educators in general as there are different views or perspectives. Herschbach (2009) suggested there are two common views of technology: an engineering view and a humanities perspective. The engineering view is referred to as the instrumental perspective (Mitcham 1994; Feenberg 2006), while the humanities view focuses on the human purpose of technology as a response to a specific human endeavor. We noticed that generally teachers who are new to the profession feel comfortable in integrating technology, which is viewed as high-tech tools (e.g., computer, smartphone and tablet), in the classroom. Experienced teachers—Yui, for example--replied that applying engineering design in her lesson is a way of integrating technology because students know how to use things around them to find a better solution to a problem. In this case, all materials that are made by humans are considered "technology". This dilemma is still being debated among educators.

In our study, all participants view technology as artifacts or tools. Adding technology from a humanities perspective may be critical for teaching STEM in an integrated approach because this view is associated with awareness and attitude about technology values and technology development. Moreover, we found that teachers often have a vague understanding about engineering and technology terms. This is similar to what Barak (2012) suggests, that engineering and technology are so closely related that they should be taught in unison within technology education. This is an interesting point about how to support teachers' conceptualizing appropriate technology and engineering terms for application in their instruction to develop all of the necessary aspects of teaching STEM education. Thus, not only content knowledge alone can bring teachers to that goal; PCK and practice need to be considered as important keys for teacher development.

Implications

Our findings suggest that effective STEM teaching requires a set of abilities of teachers such as posing challenging questions to motivate students, creating authentic STEM learning context, engaging students in a design process, and connecting activities to relevant content within STEM and other subjects. For a suggested area of research, we believe the characteristics that are claimed as effective practices will help educators improve their understanding about the state of STEM teaching and realistic views of STEM integration which are happening in classrooms. Moreover, teachers have different perspectives of STEM integration based on STEM lesson plans that participants developed, which indicate that STEM integration can be viewed in many ways. So, we need to figure out what the factors are that influence teachers' decision making to adopt a specific perspective from which to teach.

As for instructional policy, we noted that teachers' prior knowledge about STEM, both in terms of individual and integrated views, strongly affect their practice. To upgrade traditional classrooms to use integrated STEM practices, we need to seriously emphasize and pay attention to teacher development including pre-service and in-service teachers. The whole process of teacher preparation and development should consider how to help teachers gain enough knowledge and skills for teaching STEM activities, which are continuously changing. In addition, student achievement in all dimensions should be the main focus of establishing future policy. We agree with Sexton et al. (2014) who stated that "stakeholders accept the value of high quality STEM education for delivering not only STEM content knowledge, but also the 21st century skills that all students will need to engage as successful members in our workforce and society". However, teachers reflected after implementation that national standards, especially science, directly impacted their teaching. The Thai education system now focuses on content knowledge; for example, standardized examinations prioritize subject matter more than skills. Thus, even teachers see the value of a STEM approach but they might place it as the last choice. One of our participants Yui noted that

> *I know STEM is good for my students, but the MOE (Ministry of Education) still evaluates the quality of a school by O-NET scores (standardized examination). We (teachers) need to focus on content teaching (teaching approach) rather than skills and attitude development.*

For both beginning and experienced teachers, who attempt to teach STEM integrated lessons for the first time, they can likely use our findings to identify their teaching style and consider each dimension to figure the way to improve their instruction. In addition, those dimensions of practice can be used as exemplar cases, both weak and strong, as points to discuss in many forms such as lesson study, focus group discussion, lesson plan development session and so on. Finally, once again, we believe our constructed four dimensions of practice are not perfectly mature. It requires more research evidence to reinforce itself. Nevertheless, this can be fundamental data for improved further study about effective STEM practice.

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